

PATENT SPECIFICATION

932,481

NO DRAWINGS.

932,481



Date of filing Complete Specification : May 13, 1960.

Application Date : May 13, 1959. No. 16484/59.

Complete Specification Published : July 31, 1963.

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Index at Acceptance :—Classes 40(1), H(1C:4A:5D:6B:7B:7R:8E:12D:H14F); 83(3), N9; and 97(1), J15.

International Classification :—G08c (B23p, G02d).

COMPLETE SPECIFICATION.

Improvements in Metrology Apparatus Incorporating Optical Gratings.

I, JOHN GUILD, of the National Physical Laboratory, Teddington, Middlesex, a British Subject, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to optical gratings and their use in metrology, more especially in relation to the monitoring and control of moving or adjustable parts of machines such as machine tools.

It is already known to employ optical gratings as components of or auxiliaries to machine tools in order to measure and control the motions of the various parts of a machine tool, two gratings (a scale grating and an index grating) co-operating to form moiré fringes. It has been proposed to make both gratings transmission gratings and it has also been proposed to make one a transmission grating and the other a reflection grating. At least one of the gratings (the scale grating) has of necessity to be of considerable length, i.e. the length of traverse of the part of the machine tool that is to be controlled. Transmission gratings can only be made satisfactorily on glass or silica, or on a glass or silica substrate, for reasons of stability; hence if the longer grating is a transmission grating it is fragile and great care is required in building it into the machine and protecting it against hazards that may occur in use.

The above mentioned disadvantage is avoided if the longer grating is a reflection grating because this can be made on a non-fragile material such as metal while the transmission grating will be a short grating (usually the index grating), and can therefore be more readily and cheaply replaced in case

of damage. The transmission grating may be traversed over the reflection grating, the former being attached to a moving and the latter to a relatively fixed part of the machine to be controlled or monitored. However, in many cases it may be desirable to have the transmission grating fixed and the reflection grating movable as in this way the optical and electrical equipment associated with the index grating, and used for counting the passage of moiré fringes as the two gratings are moved relatively to one another, may be maintained stationary, with consequent simplification of electrical connections.

While the use of a reflection grating overcomes the disadvantage of fragility, it brings its own problems. Thus, if the reflection grating is of specularly reflecting material, the transmission grating is mirrored in the reflection grating and though serious complication of the resultant moiré fringe system due to interaction between the image grating and the scale grating could be substantially eliminated by maintaining the planes of the two scale gratings very accurately parallel, the present invention substantially eliminates the disturbing image of the transmission grating by giving the reflection grating a diffusively reflecting background instead of making it specularly reflecting. In this way these difficulties of maintaining very accurate parallelism which are increased by the fact that one of the gratings has to be moved in relation to the other, are overcome.

The reflection grating is desirably of the bar and space type, the spaces being diffusively reflecting.

The reflection grating (normally the long grating) may be formed on any suitable material, but desirably on metal, because of its

robustness, stability and ease of fixing. Moreover, the metal may be of any convenient thickness and in some applications may be in the form of a flexible tape which will allow it to be accommodated on reels or pass readily over rollers.

The diffusively reflecting surface may be provided in the case of a metal support by first preparing it with a coat of matt white enamel before generating the grating upon it. This is particularly suitable for a support made of stainless steel, the common cutlery grade of which is very suitable. As well as the obvious advantage of resistance to corrosion this material has a coefficient of thermal expansion of the same order as the material commonly used for the larger parts of machine tools and other machines on which the invention might be employed. Hence the chance of buckling or cracking of the reflection grating due to temperature changes is minimised.

Another suitable material is aluminium, in which case it may first be prepared by anodising and dyeing a suitable colour, say black or white, before generating the grating upon it.

When one of the gratings is a reflection grating both the incident and emergent beams are on the same side of the gratings, and this presents further problems in the disposition of the light source and detector. For all but gratings of very coarse pitch, the incident beam must be collimated by a lens between the light source and the transparent grating. According to the invention the incident beam is so directed that for the emergent beam or a selected part of it the angles of incidence and emergence are equal to which end the emergent beam must return substantially along the incident beam. Thus the reflected beam or the selected part of it returns through the collimating lens by which it is brought to a focus in the focal plane of the lens. If the gratings are of coarse pitch the total emergent beam passing through the lens will comprise beams of several orders with very little divergence, in which case it is practicable and usually convenient to utilise all of them by the use of a detector of appropriate size. But with gratings of finer pitch for which the emergent beam as a whole comprises beams of various orders with appreciable divergence it is desirable to utilise one beam only in order to get moiré fringes of good contrast. The selected beam will usually not be the zero order beam and for a beam of any other order to have equal angles of incidence and emergence it must return substantially along the incident beam.

In either case the further problem then arises of separating the positions in space of the lamp and detector. One solution provided by the invention is to incline the inci-

dent beam to the plane perpendicular to the rulings and to the grating surface. The emergent beam will then be equally inclined to the other side of this plane. Although the inclination must be small to enable the one collimating lens to intercept both the incident and emergent beams, the focused spectra can in this way be separated from the lamp sufficiently to accommodate a small detector.

Another solution consists in introducing some form of beam splitter such as a part transparent mirror between the lamp and collimating lens. A scanning head consisting of lamp, beam-splitter, lens and detector may be built into a compact rigid unit capable of rotation about an axis parallel to the grating rulings so as to enable the angle of incidence to be adjusted to any required value while maintaining coincidence of the directions of the incident and reflected beams.

Turning now to the production of the reflection gratings, there are many known ways of producing such a grating on a surface, e.g. of metal. The classical method of engine ruling could be used but has the disadvantage that very complicated and expensive equipment is needed to produce a grating of high accuracy. It is preferred therefore to generate the grating by a photographic process. By way of example a process will now be described which has been used with success.

A master transmission grating of suitable length may be prepared according to the invention of U.K. Patent Specification No. 817,051. The surface on which a reflection grating is to be generated is coated with a thin layer of bichromated fish glue to which a small proportion of ammonia has been added. The master grating is then imaged on to the glue surface using illumination rich in ultra-violet rays. Where the rays fall, the glue undergoes physico-chemical changes that render it insoluble. When the exposure is completed the glue surface is washed and the soluble glue is thereby removed. The remaining insoluble glue is then carefully heated to a temperature of the order of 250° C. This causes part of the glue to carbonise and the result is a series of black lines on a light background, forming an optical grating. Alternatives to carbonisation comprise applying printers' ink to the remaining glue or etching the metal or anodised surface unprotected by glue.

It is generally easiest to generate and reproduce gratings with a moderate number of lines per inch, say from 100 to 5,000, though the present invention is not restricted to that range. With straightforward moiré fringe methods the use of a small number of lines per inch restricts the resolution of the system. However, the present

invention enables a reflection grating to be used in the technique set out in U.K. Patent Application No. 20569/58 (Serial No. 932,471) whereby, with the use of a third grating, interpolation to any required degree of fineness may be obtained between moiré fringes produced between relatively coarse gratings. The first and second gratings of the basic method have the same line spacing, but the third grating, which coacts with the long (reflection) grating, has a different line spacing. If, for example, the first and second gratings have 100 lines per inch and the third 101 lines per inch the relation between the two moiré fringe systems produced is such that interpolation between fringes produced by the first and second gratings may be carried out to one hundredth of a fringe spacing, with consequent improvement in resolution. The scheme may be likened to the use of the Vernier.

The present invention may be applied to almost any machine tool or other machine presenting similar control or monitoring requirements. Thus a screw cutting lathe could be servo-corrected by means of a signal derived from two other signals; one produced by the rotating headstock, the other by the linearly moving saddle. One or both signals may be derived from the coaction of two optical gratings; linear gratings for the saddle and radial for the headstock. The present invention enables one of the gratings, in either situation, to be in the form of a reflection grating, more especially the long scale grating associated with the saddle as described.

WHAT I CLAIM IS:—

1. Metrological or control apparatus employing a pair of relatively moved optical gratings one of which is a reflection grating in which the reflection grating has a diffusely reflecting background.

2. Metrological or control apparatus according to Claim 1 in which the reflection grating comprises specularly reflecting bars alternating with diffusely reflecting spaces.

3. Metrological or control apparatus according to Claim 1 in which the reflection grating comprises absorptive bars alternating with diffusely reflecting spaces.

4. Metrological or control apparatus according to Claim 1, 2 or 3 in which the reflection grating is marked on a metal support first prepared with a coat of matt white enamel before generating the grating upon it.

5. Metrological or control apparatus

according to Claim 4 in which the metal is stainless steel.

6. Metrological or control apparatus as claimed in Claim 4 in which the reflection grating is marked on an aluminium support first prepared by anodising and dyeing before generating the grating upon it.

7. Metrological or control apparatus according to Claim 4, 5 or 6 in which the reflection grating is in the form of a flexible tape.

8. Metrological or control apparatus according to any preceding claim in which the lines of the reflection grating are produced by photography.

9. Metrological or control apparatus employing a pair of relatively moved optical gratings one of which is a reflection grating, or apparatus according to any of the preceding claims, in which the incident light is passed through a collimating lens between the light source and the transparent grating and the incident beam is so directed that for the emergent beam or a selected part of it, the angles of incidence and emergence are equal and the emergent beam returns substantially along the incident beam.

10. Metrological or control apparatus according to Claim 9 in which the incident beam is inclined to the plane perpendicular to the rulings and to the grating surface, the inclination being small enough to enable the collimating lens to intercept both the incident and emergent beams but sufficient to separate the focused spectra from the lamp to enable a detector to be located in the focused spectra.

11. Metrological or control apparatus according to Claim 9 in which a beam splitter is introduced between the lamp and collimating lens thereby spatially separating the image obtained by the coaction of the two gratings from the light source.

12. Metrological or control apparatus according to Claim 11 in which the lamp, beam splitter, lens and a detector are built into a compact rigid unit capable of rotation about an axis parallel to the grating rulings to enable the angle of incidence to be adjusted to any required value, while maintaining coincidence of the directions of the incident and reflected beams.

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